

Simulation of Stirling engine working cycle

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Abstract

This paper describes model of Stirling machines. The model will be used for optimalization of power station. The power station consists of Stirling engine and electric generator. The genetic algorithms can be used for identification parameters of engine.

1. Introduction

The engines with external heat inlet were never widespread in the past [3] except steam engine. Nowadays, it is necessary to solve some global problems and to look for new alternative sources of energy.

The aim is a design of small combined heat and power unit which is driven by Stirling engine. Achieving of good thermodynamically Stirling engine efficiency represents relatively difficult optimizing task. The design of accurate thermal model is very important. We cannot neglect many heat losses, so the theory of ideal cycles is not usable. The computational models dividing working gas volume into two or three sub-areas are not too accurate. The engine dividing into many volume elements (final volumes method) makes better results. There are few simplifications of gas properties in the model. The above mentioned method of calculation does not achieve the CFD accuracy. However, this model is faster and more suitable for future optimalization of engine parameters.

2. Thermal model characteristic

The properties of the developed Stirling engine model (μ -modification) are as follows:

- Numerical model is used. It is able to simulate non-stationary and transient processes.
- The ideal gas, for which the state equations are applied [2], are considered as working medium.
- The friction and inertial forces are not considered in working gas.
- The leakages of the gas from engine working part are not considered.
- The pressure losses due to displacement of the working gas are omitted, the same holds for the gas warming due to friction.
- The model so far does not include the re-generator of the working gas temperature.
- The engine is divided into volume elements for thermal processes modelling (final volumes method), see fig. 1

3. Numerical calculation system of this model

The Stirling engine model is represented by system of several non-linear differential equations and by another auxiliary relation. The regular dividing of the engine makes possible using of the matrix system of many variables. The main calculation is solved by numerical integration with fixed time step [4]. For calculation of some variables we must use results from previous step because actual value has not yet been calculated. Errors due to this fact are negligible at sufficiently small time step.

Three related problems are solved in this iteration calculation:

- 1) The behaviour of working gas temperatures and pressure. The pressure value is used for output power determination.
- 2) The determination of working gas flow among gas elements. It is solved by using other sub-iteration cycle.
- 3) We must still consider the thermal processes in solid parts of engine in each solution step. The interaction of solid parts elements is solved by thermal network method.

We consider also addition of electrical generator model. The whole model is implemented in MATLAB software.

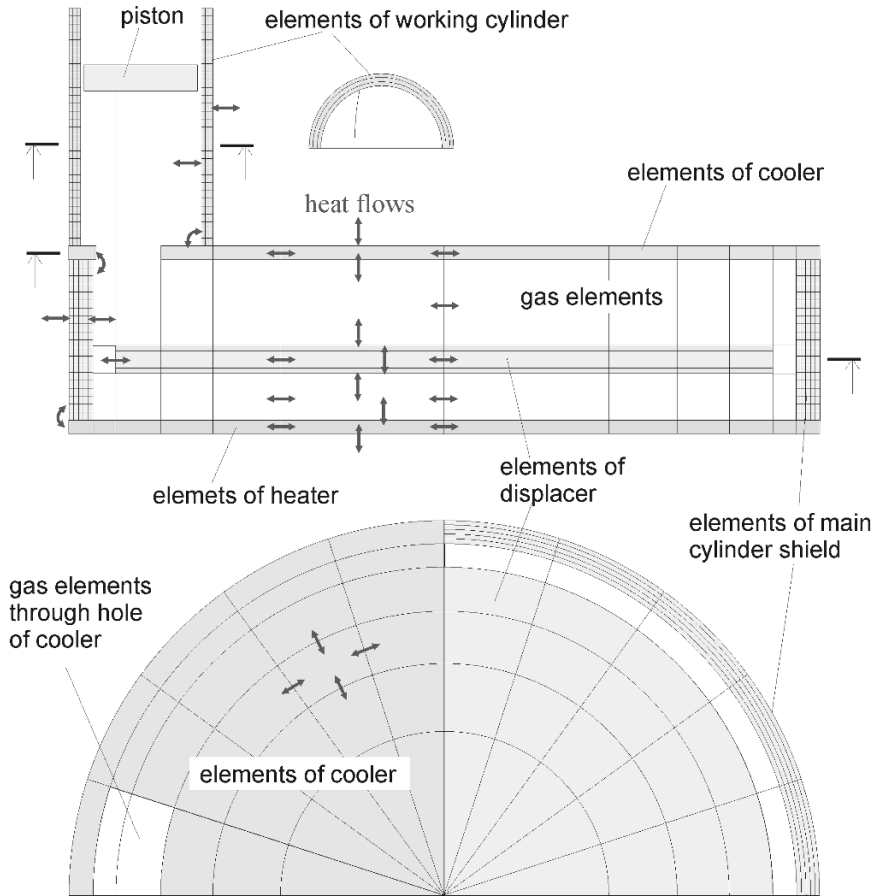


Fig. 1. Small sample Stirling engine division to elements

4. Simulations results

The input parameters correspond with dimensions and properties of Stirling engine small real model. The values of some parameters have been only estimated (e. g. heat transfer coefficients) and these parameters should be verified by experiments.

Figure 2 show the time (and crank tilting angle) relations of torque, pressure and temperatures of working gas in two crank movements. These temperatures belong to elements: under the displacer, above displacer and in working cylinder.

Figure 3 shows distribution of temperature and weight flow for tilting crank angle 198° from its upper dead point. (the displacer goes up, the piston goes down).

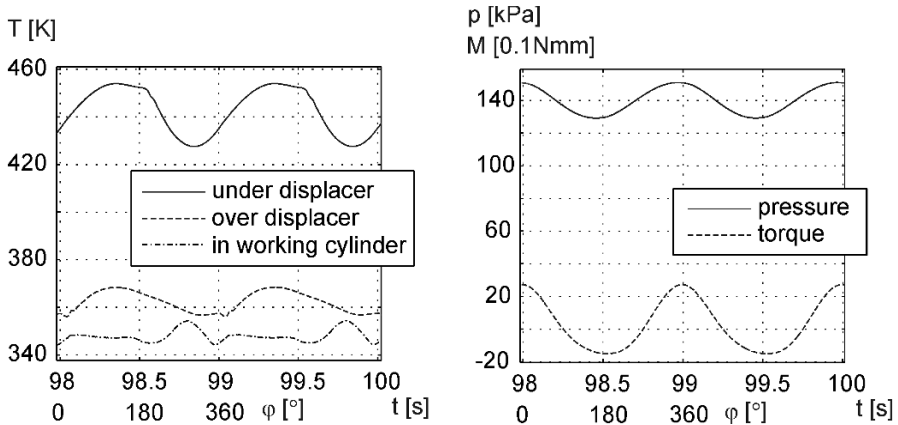


Fig. 2 The temperatures of working gas (left). The pressure and engine torque (right), all in relation of time and of crank tilting angle of displacer.

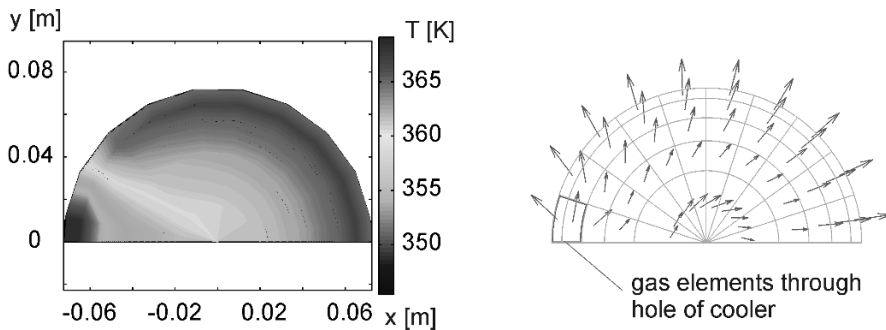


Fig. 3 The gas temperatures (left) and the vector field of weight flow above the displacer (right).

5. Optimization by using genetic algorithm

The maximal power output and efficiency of the combined heat and power unit are our aims. We must find the parameters of engine which give the best compromise of both requirements. An extensive zone of good efficiency is not necessary, because one operating point is supposed. The design of engine is naturally limited by weight and dimensional requirement.

The resulting virtual model will work with many variables and parameters which determine engine behavior. We can sort these parameters into two classes:

-the parameters given in advance – e. g.: the maximal and minimal temperatures, the mean value of pressure, the properties of working gas and materials, minimal required power output, the main dimensions, characteristic of generator.

-the variable parameters – e. g.: some dimensions, the angle between cranks, the area and volume of regenerator, etc.

Using of genetic algorithm is planned for finding of variable parameters optimal values. The success of design will be determined by simple function which will evaluate (by numerical weights) results of simulations. The model with designed parameters will be used. We will have to evaluate especially the efficiency for set power, the output power for maximal efficiency, the important dimensions, etc.

6. Conclusion

The biggest disadvantage of built numerical model is determination of heat transfer coefficients between solid parts and gas. The existing empirical formulas for it's determination are usable in the specific conditions. They are not mostly realized in Stirling engine. Therefore, we should estimate the coefficients by using experiments or FEM software. Then, the numerical model will be considered like adequately accurate.

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References

- [1] M. Jícha "Přenos tepla a látky" Akademické nakladatelství CERM, Brno, 2001
- [2] M. Pavelek "Termomechanika" Akademické nakladatelství CERM, Brno, 2003
- [3] G. Walker "Stirling-cycle machines" Clarendon press, Oxford, 1973
- [4] B. Maroš, M. Marošová "Základy numerické matematiky" PC-DIR Real, Brno, 1999